STRATEGIES AND METHODS FOR THE OPTIMAL INTEGRATION OF DISTRIBUTED GENERERATION PLANTS INTO THE LV AND MV DISTRIBUTION NETWORK: ENEL DISTRIBUZIONE EXPERIENCE AND FUTURE PROSPECTIVES

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ABSTRACT

Strong incentives and the general impulse to the distributed generation plants (DG), particularly from renewable energy sources, have revealed quickly and dramatically the issue of their connection and integration into LV and MV distribution networks, traditionally planned, built and operated to get energy from transmission networks and deliver it to end users.

In this paper, Enel Distribuzione's strategies and methods in defining solutions to connect DG are presented. These are not only derived from experience of Enel, but also by specific studies and field measurements, and they are implemented because phenomenon of DG not only does not cause issues but may bring, if possible, benefits to the distribution network and to the electrical system as a whole.

INTRODUCTION

The electricity distribution network, for its bidirectional nature, is able to accommodate, for how it was conceived, also the limit amount of generation equal to the amount of power loads to be fed, even without functional or structural modifications. Under these conditions, DG "helps" the network in feeding loads and therefore bring benefits in terms of reduced losses, reduced energy production from traditional power plants, lower structural investments otherwise needed for the grid.

The huge number of connection requests in the last two years, so high to overcome, in terms of required power and only in the distribution networks, twice the national demand, has obliged not only to plan dedicated network infrastructures – i.e. new HV/MV substations for the transmission of energy to higher voltage levels - but also to a more and more accurate phase of technical study for the connection to avoid devastating impacts on the existing network mainly in terms of:

- voltage quality;
- number and duration of interruptions;
- fault management systems;
- transport capacity of the network;
- safety of electrical system.

As a consequence of the huge number of DG connection requests, most of capacity of the network has been "engaged" by Producers that have already accepted a technical solution. This relevant issue has led to situations where the network is defined as "saturated" (no longer able to accept new DG), but only in a virtual sense, since it is not certain that all future plants will be actually authorized/activated (the percentage of successfully activated plants is much lower than 50%), and resulted in the definition of connection solutions apparently oversized compared to the power of the individual plant to be connected.

The choice of "where" and "how" to connect DG, in most cases from renewable sources and therefore not programmable, is a duty of the Distribution Network Operator (DNO) and is essential to ensure a proper and efficient future functioning of the network and take into account several factors, not just technical (rated power, power required to be released, characteristics of the network environment, technological innovations, etc..) but also management (economic impact of new infrastructures, impacts due to regulation, impacts due to authorization procedures, cancellations and failure to carry out installations, etc...).

In the following, methods and strategies for the identification of DG connection solutions to LV and MV networks currently used by Enel Distribuzione are presented.

DATA REQUIRED FOR TECHNICAL ANALYSIS AND FEASIBILITY STUDIES

In general, the following information on DG are required for defining a connection solution:

- number, type and rated power generators to install, their primary source of power and contribution to short-circuit currents;
- the power requested by the producer to be injected on the point of connection;
- contractual power already available in the connection point if the plant is already connected, even if it is only an end user;
- technical characteristics of user's network.

User data are made available to the network operators by

mean of the module sent for requiring the connection of the plant.
It is also fundamental to detect the existing network to which it is assumed to connect the DG and on which the technical analysis will be carried out.
According to Technical Standards, the DG integration in the network must not create issues to users not only already connected, but also planned to be connected to. Therefore, technical analysis should be performed on a network in which planned works, loads and generators are already included. This is also important to avoid further verifications and re-plan of works already designed or even in progress.
The characteristics of existing and planned networks (routes, electrical and mechanical characteristics, devices, etc..) are stored in two large databases (one for LV and one for the MV) and therefore easily acquired.
Another fundamental aspect is the collection of load data.
In order to realistically simulate a possible future network condition, loads are calculated on a statistical basis by means of utilization coefficients, different for each type of load (domestic, rural, industrial, etc.), applied to the contractual powers of each individual user. These coefficients are determined on historical load curves measured on different types of users and, for the MV network, also based on the conditions of maximum load[1] on the existing network. By means of the coefficients to be applied to individual network nodes (LV users if the study concerns the LV network, MV users and MV/LV substations if the study concerns the MV network), it is possible to simulate a good approximation of the load conditions also on a planned network, regardless of its structural or topological set.
The network to be analyzed includes the generating capacity already connected and that for which the solution has been already established on the same network. Energy produced by planned DG will be took into consideration depending on the type of analysis to be carried out, as it will be described in the following. In any case, the utilization coefficient associated with the planned DG is always equal to 1 (the total power requested to be injected to the network will be considered), by virtue of the fact that DG on MV and LV networks is generally not programmable and network must be always able to accommodate the whole power required to be injected.

CHOICE OF THE TECHNICAL SOLUTION

The technical solution for the connection of the DG to the network is usually defined, except for particular producer's claims, on the basis of a policy called "technical minimum", defined as the solution for the connection of a user/ producer such that the level of economic and technical works to be executed is less than other possible connection solutions. This solution may also include work on existing network. The technical minimum must also be:

- technically feasible;
- achievable;
- able to accommodate the full power required by the user (except for those cases disciplined by Regulator's Acts);
- compatible with technical and operational standards in use.

According to existing Technical Standards and Regulatory Acts, a minimum technical solution is identified on the basis of standard and healthy conditions of the network (N conditions).
In general, the procedure to be followed to determine the technical minimum solution for the connection of DG consists of the following steps:

1. choice of the insertion point on the existing network, assumed to be appropriate for the connection, nearest to the DG under study;
2. choice of connection scheme;
3. feasibility study;
4. if 3 is successful, then the connection solution is identified;
5. if 3 fails, the process is repeated by choosing another connection point, possibly on other LV or MV lines;
6. if results of the feasibility studies on existing network are negative, but it is assessed that a reinforcement of the network appears technically / economically viable to eliminate the critical problems, tests as per section 3 are repeated considering that works on the network;
7. if feasibility studies on existing network fail, even considering network reinforcements, may be needed to provide a solution which includes new LV or MV feeders from substations. Otherwise, may be needed to consider works on higher voltage networks (substitution of existing transformers, new transformers on existing substations, new MV/LV or HV/MV substations).

Voltage level of the connection

The current regulation in Italy defines power ranges on which the connection to a certain voltage level is mandatory:

- power required to be injected to the network ≤ 100 kW: LV network connection required;
- power required to be injected to the network ≤ 6.000 kW: MV network connection required (except what stated before).

Between 100 and 200 kW, the choice of voltage level of connection (LV or MV), and between 6.000 and 10.000 kW (MV or HV), is operated by the DNO in accordance with his criteria.

Connection scheme

When identified an insertion point on the existing network, it must be defined how to connect the DG and the network

1 maximum load on MV network is defined as the 98th percentile of the load measured along a year over that network.

plant for the connection (i.e. derived from the line with or without disconnection devices, directly connected to an existing or new substation, in-and-out from the line). Factors affecting the choice are the distance of the DG from the existing network, the network topology, its structure (overhead or underground) and its degree of automation. The choice must be made taking into account the planning criteria in use.

Where there are a huge number of connection requests of nearby DG plants received in a limited time, it is desirable to choose the connection scheme considering all future facilities, expanding the concept of minimum technical solution to the whole system, in order to plan the future network in a rational way. For example, the study for the connection of three nearby plants of 3 MW each, with the old criteria, would lead to the planning of three different new MV feeders from one or more primary substation. Instead, it's more rational and efficient to connect them to a single new MV feeder. To provide a common network for several DG plants is possible only under certain circumstances: due to the possibility given to DG owners to build MV and HV network plants for the connection and to the high rates of connection requests waived, an effective coordination between DNO and involved producers is needed in order to successfully complete the works and avoid the construction of oversized or even not useful infrastructures.

Network developments

Together with the definition of the technical solution for a DG plant, the possibility of identifying network development works has been introduced, in order to promote its rational development and to improve the quality of service for all kind of users. In this category are included all those works that are not strictly required for connection of the DG but are consequential to their implementation in order to ensure optimum operation of the network even in faulty conditions (N-1 conditions).

Example of development works: where a DG plant has to be connected to a MV feeder which already has more than 60% of its capacity in the worst conditions reserved for one or several generators to connect or already connected, realization of a new feeder joining the existing one as backup can make possible to properly operate the network even in N-1 conditions.

End of development works must not be a requirement for the activation of the DG. However, it is crucial to identify those works in the technical solution as their authorization process could be faster if conducted by the Producers.

Feasibility study

The analysis is needed to check if a given technical solution for the connection of DG is compatible with the network. It takes into account the following aspects:

1. slow and rapid voltage changes across the network affected by the DG connection;
2. network capacity;
3. DG's contribution to fault currents;
4. self excitation of the asynchronous generators.

The connection of the DG at a given point in the network is subjected to the successful conclusion of all the tests described below, performed with dedicated software.

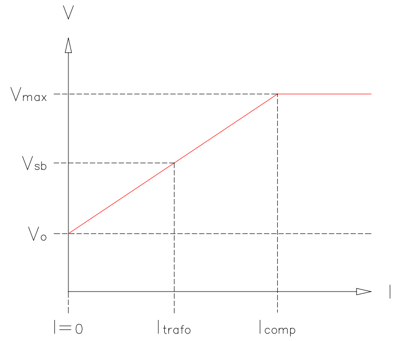
Tests on voltage levels

The purpose of these tests is to ensure that, following the insertion of DG, the voltage supplied to the network users involved and its variations are within the limits given by national and international Standards (EN 50160) and by the connection agreement between DNO and users.

Since the voltage regulation strategies on the transformers are different between LV and MV networks, tests will be described separately.

Tests on MV network:

The voltage regulation on the MV network is done using the OLTC installed on HV/MV transformers. The characteristic of the voltage regulator currently in use in Enel is this kind: $V_{sb} = V_0 + R_{comp} \cdot I_{trafo}$ and it is shown in the figure below.



The slope of the feature (parameter R_{comp}) is currently defined for every transformer on the basis of the underlying network and connected passive loads, and it is set to keep the voltage on all nodes as constant as possible under all the passive load possible conditions.

It is remarkable that in the case of negative current on the transformer (significant presence of DG, such as to overcome the passive load), busbar voltage is constantly kept equal to the set point V_0, whatever is the current value. Connected DG decreases the current flowing through the HV/MV transformer: the voltage regulator understands it as a reduced passive load and drops the voltage on the MV busbar, affecting voltage profiles with the risk of going under the limit values, especially along feeders without DG underlying the same MV busbar.

As a consequence, major variations in voltage on the MV nodes occur in conditions of maximum passive load and with all the DG (already connected and expected) activated in the network. Voltage tests check that these variations are within the range +/- 5% in order to ensure also that LV users underlying MV/LV nodes are supplied with a voltage respecting the limits. Furthermore, it is checked that the voltage on all MV nodes is within the range +/- 8% V_n in extreme network conditions (maximum and minimum load and overall presence of DG).

With regard to the rapid voltage changes, in accordance with the new edition of EN 50160, voltage tests check that connection and disconnection of the DG object of study does not cause voltage variations on all existing MV network nodes above the 6% V_n, without the OLTC to intervene. Reference condition for this case is maximum load and maximum generation and only the DG object of the study is operated (this condition has been experimentally defined taking into consideration the results of measurements on different solar farms installed in nearby areas).

Tests on LV Network

The voltage setting on the LV network is done using the voltage regulators placed on MV/LV transformers. The transformation ratios can not be changed under load so, for the purpose of these analysis, a fixed ratio is set.

For each node of the LV network, voltage tests check that the contribution of the generator is not likely to cause voltage variations greater than 8% V_n in extreme conditions of minimum load and maximum generation. This condition is simulated by placing the whole generation active, already present and planned, and loads values of 30% of their maximum calculated through the utilization coefficients.

Tests on network capacity

The energy flows caused by the presence of DG can exceed the thermal capacity of the conductors. The purpose of these tests is to check whether the contribution of DG to be connected is likely to exceed the following limits, as a percentage of the thermal limit current of the conductors:

- 80% on MV networks with generation and loads;
- 100% on MV networks with only generation;
- 60% on LV networks.

Saturation of transformers

In areas with high concentration of DG (already installed and/or planned), it is possible that the power fed into the network itself is comparable to the rated power of transformers. Where the power flow through the transformer exceed the 90% of its rated power, it is needed to upgrade existing transformations (e.g. through the replacement of transformers with other higher-size) or even the construction of new primary or secondary substations. Where works at higher voltage levels are needed, the underlying network is defined as saturated.

Tests on DG's contribution to fault currents

In this tests, it is verified that the contribution of DG in terms of fault current is such to keep the values of short circuit currents in the network:

- compatible with the characteristics of network breakers;
- compatible with the network protection system (in particular to ensure the coordination between the protection devices);
- are not likely to exceed the limit value of I^2t for the conductors.

Furthermore, with regard to the MV network, is checked that the contribution of DG to the phase to earth fault current do not exceed the limits of compensation for the neutral grounding systems installed in primary substations. If limits are exceeded, and this is only due to the DG object of study, as well as definition of work on the existing network or another technical solution, the Producer may be required to install systems limiting the contribution of its DG to fault currents.

Self-excitation of asynchronous generators

Purpose of this test is to check whether there is a possibility of self-excitation for asynchronous generators due to the capacitor banks that may have been installed in order to bring the power factor within specified limits. The self-excitation of asynchronous generators can result in unintentional islanding of the generator itself.

DG DEDICATED INFRASTRUCTURES

The number of connection requests to DG in some areas are likely to far exceed the load around. Usually, these situations result in conditions of network's saturation, and therefore lead to works on higher voltage network to overcome the technical limitations of the existing one.

In order to better integrate the DG and to allow network's operation limiting disturbances to existing passive users, MV and/or LV networks dedicated to DG are designed, and in some cases already implemented. As for the MV networks, the construction of a new infrastructure from scratch is allowing the use of innovative components and equipment for a secure operation of the power system and an "active" participation of the DG. In particular:

- primary substations to which these dedicated networks are underlying (known as DG collectors) feature an integrated and smart system of protection and control of the network and energy dispachment. Due to the impact of the DG on the transmission system to which they relate, the specifications of DG collectors and their interoperability with HV network have been standardized by mutual agreement with the TSO.
- The MV networks are entirely build with underground and overhead cables, to ensure high standards of service and to respect the environmental constraints often imposed by local authorities.
- Nodes along the MV feeders are equipped with new generation of MV switchers carrying a protective system and communication interfaces. In particular, these components enable the automatic network reconfiguration in case of failure, the dispatching of energy and the acquisition of signals from the DG.
- The communication system between DG collector, MV nodes and DG is achieved through optic fibers laid along the conductors, thus forming a reliable, fast and dedicated communication system.

CONCLUSIONS

Integration of DG into distribution network is a relevant issue and must be performed properly in order to ensure a safe and effective operation of the power system. Enel Distribuzione's best practices have been here described, but they only form a basis to develop network innovations that will allow in the future the expected fully integration of DG.